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AUTHOR Bunderson, C. V.; And Others
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ABSTRACT

WICAT Systems, Inc., produced a "proof of concept" instructional videodisc in college biology with support from the National Science Foundation. The project involved simultaneous development of content design, instructional strategies, software, and hardware, with a principal focus on evaluation of the instructional videodisc in the classroom. Videodisc development proceeded through three phases of increasing sophistication and evaluations were performed at each phase, including several comparisons of student learning with videodisc instruction and traditional lecture learning which were conducted at three different colleges. Results indicate that videodisc students consistently displayed greater learning and retention gains, reduced study times, and higher productivity ratios. This paper describes the evolutionary stages of development of the intelligent videodisc, "Development of Living Things," and the parallel evaluation studies. It also includes a discussion of instructional theory and its implications for machine-mediated learning. Ten data tables and a list of references are provided. (JB)

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Instructional Effectiveness of an Intelligent Videodisc in Biology

C. V. Bunderson, B. Baillio, and J. B. Olsen

WICAT Systems, Inc.
Orem, Utah

with

J. I. Lipson

WICAT Systems, Inc.
Orem, Utah

K. M. Fisher

Division of Biological Sciences
and Department of Education
University of California
Davis, California

Abstract WICAT Systems, Inc., produced a "proof-of-concept" instructional videodisc in college biology with support from the National Science Foundation. Student learning with videodisc instruction was compared to traditional lecture

Note: The first three authors were responsible for the conception, implementation, and evaluation of the project described in this paper. The last three authors (Olsen, Lipson, Fisher) reviewed the videodisc, experimental results, and annual and final reports produced by the project and are responsible for condensing the information into this paper. Lipson and Fisher take primary responsibility for the section on the theory and implications.

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learning in introductory biology courses at three different colleges. *Videodisc students consistently displayed greater learning and retention gains, reduced study times, and higher productivity ratios.* This paper describes the evolutionary stages of development of the intelligent videodisc, "Development of Living Things," and the parallel evaluation studies. It also includes discussion of instructional theory and its implications for machine-mediated learning.

Introduction

The potential of a new technology is usually not clearly and precisely understood when it first appears. Rather, people have a vague intuition that the new technology "ought" to have important uses. Only with time and a great deal of play, exploration, and imagination do we winnow out its most practical and suitable applications. For example, when the laser was invented about 30 years ago, people thought that it would be a miraculous tool. However, it has taken most of the intervening decades to develop lasers into a major technology.

The computer-controlled videodisc is sufficiently different from all preexisting technologies so as to present a major challenge to those who wish to use the medium for the delivery of instruction. The intelligent videodisc system is an interesting blend of image storage technology and computer technology. The computer can be directed to show each of 54,000 images on each side of the videodisc. In effect, it is a picture book containing 108,000 pictures, or the equivalent of approximately 20,000 printed text pages. If the pages of a picture book are shown rapidly (30 frames/sec), the illusion of motion results, as with film. When the 30 frames per second are being shown, the electronic system can detect and reproduce a two-channel sound signal that is embedded in the video signal. At this speed the program on one side of a videodisc is completed in one-half hour (54,000 frames ÷ 30 frames/sec ÷ 60 sec/min = 30 min). The two audio channels can be used to provide either stereo or two sound messages. The two sound messages can, for example, be in two languages (e.g., Spanish and English) or at two intellec-

tual levels (e.g., one sound script for beginners and one for advanced viewers).

Each frame is numbered electronically and can be accessed in any order under computer control. Single frames (e.g., frame number 23,137) can be called up and viewed as long as one likes. The disc is not damaged when it "sits" on a single image, because the information is picked up by a reflected low-power laser beam. The computer can also control the disc so that each frame in a sequence can be viewed for a fixed number of seconds (e.g., 10 seconds/frame).

When videodisc technology is combined with today's enhanced computing power, the possibilities are expanded greatly. However, the computer-controlled instructional videodisc is still in the formative stage of development. The instructional courseware development tools and production techniques must become more efficient and be better molded to the needs of the instructional author/designer before videodisc technology will play a large role in instruction [1]. The value of the experiment described in this paper does not lie in the particular lessons that were developed. Rather, its importance lies in its exploration of how to make use of this powerful technology.

WICAT Systems, Inc., produced a "proof-of-concept" instructional videodisc in college biology with support from the National Science Foundation (Grant No. SED–790000794). The project involved simultaneous development of content design, instructional strategies, software, and hardware, with a principal focus on evaluation of the instructional videodisc in the classroom. Videodisc development proceeded through three phases of increasing sophistication, and evaluations were performed at each phase, including several studies of comparative achievement. The results are presented here.

The paper begins with consideration of some of the general issues surrounding machine-aided learning. It then describes the objectives of the WICAT project, the development of the videodisc, and the evaluation design. Evaluation methods and results are described in the next section. The paper ends with a discussion of the next stages of development.

Theories, Models, Questions, and Implications for Machine-Aided Learning

In order to think about the implications of this prototype videodisc for machine-aided learning, an explicit model of the human learner is needed. At present there are models of human information processing in limited domains (e.g., algebra problems, chess, reading) and models to account for certain specific aspects of learning (e.g., Piaget's model). Yet to our knowledge there are no theories that attempt to account for the full range of human learning behavior, or that attempt to explain *why* as well as *how* people learn in various situations. Lacking such a model, we will list some dimensions or elements that seem important and interpret the research findings in light of these dimensions.

Integration

Human beings evolved using the full range of their senses and associated brain power. Yet our classrooms have become barren, left-brain deserts, filled with words and symbols that are divorced from the images and events they represent. This has happened even though people seem to crave and respond strongly to visual images. Students in our project seemed hungry for the videodisc to balance the skewed verbal diet of academia with a rich supply of visual images. The videodisc can appease that hunger to some extent, but two considerations prevent it from being a "perfect" solution. One is the initial cost of production of moving images. The other, and probably greater, limitation is the fact that moving sequences gobble up disc space, trading away 54,000 still frames for a mere half hour of motion.

Emotional Factors—Aesthetic and Social

All of us are bombarded by more signals than we can process. Therefore, we need some rules or algorithms to determine what we will pay attention to and what we will remember. Evidence suggests that emotions play an important role in this process.

Material that is attractive, appealing, humorous, compelling, or challenging is more likely to command and hold our attention than are dull, dry presentations. The social milieu is another factor that affects emotional response. We are more likely to pay attention to an event if those around us view it as important. Our perception of what others expect strongly influences our behavior. Thus, commitment and persistence typically improve if students are embedded in a social network in which people express high expectations for and interest in the students' performance.

Thus, emotion facilitates the focusing of attention on the learning task. Potential sources of emotion include fear, social pressure, the desire to improve oneself, the perceived beauty of the thing to be studied, the desire to please someone or some group, the desire to master a skill, and intrinsic satisfaction in the learning activity. To the extent that we want to assure learning for a wide range of personalities or students, we need to be aware of facilitating emotional factors that appeal to most students, or we need to have a system that tailors emotional incentives to the characteristics of the individual student.

The videodisc may appeal to and stimulate a wider range of emotions than classroom presentations for at least four reasons: (1) its novelty; (2) its perceived importance as an instructional medium; (3) the power of the visual imagery, especially of events that are normally not visible (e.g., cell division) or that are inaccessible (e.g., mating rituals of various animals); and (4) the rich interplay of styles of presentation.

Building on Existing Knowledge and Experience

Each person has a rich model of the world based on his or her sensory experiences and the way he or she uses these to create a network of concepts. The concept network helps one to allocate attentional resources and to classify and interpret events. That is, a learner interprets new words, concepts, and experiences in terms of a previously acquired model of the domain. Similarly, a lesson uses definitions, examples, analogies, and explanations to explicitly build on previous learning and experience (in addition

to providing new primary experiences). A successful lesson challenges the learner and includes just the right amount of novelty and unpredictability, while not swamping the student's information-processing system with too much information, too many new concepts, or too great a degree of complexity. In short, a lesson builds on what the student already knows. New ideas and procedures are introduced at a pace that allows the student to absorb and integrate the new material into his or her conceptual and procedural mental network.

Because of the relative ease with which the videodisc can provide visual presentations, including both still and moving images of various types (e.g., realistic photographs, films, animation, diagrams), it offers these potential advantages over lecture teaching: (a) more and richer illustrations of new concepts and (b) more visual interpretations of the words, phrases, and examples used to develop the new concept. There are many complex issues regarding optimal deployment of words and images. However, a judicious combination in videodisc instruction may be able to trigger a greater range of preexisting concept networks in students' minds than could a presentation limited to spoken and written words and simple diagrams. This may have been a contributing factor to the increased levels of confidence in biology, decreased study time, and improved achievement scores that students displayed in the biology videodisc project.

Representations

The representation of information—words, symbols, drawings, diagrams, tables, charts, graphs, and photographs—can make a significant difference in a student's ability to (a) understand an idea or (b) mentally execute a procedure or process (e.g., how DNA replicates itself). One of the important strengths of the biology videodisc, according to student comments, is the use of clear, comprehensible, and mentally manipulatable representations of both objects (e.g., cells and chromosomes) and processes (e.g., protein production on ribosomes). Multiple forms of representation of a new concept may help students to develop

richer concept networks and avoid misunderstandings and misconceptions.

Models of Skilled Performance

The opportunity to observe a skilled performer generally facilitates learning. One can acquire a "runnable" mental image of movements, that is, one can review the images mentally as if observing an imaginary motion picture. This opportunity to observe has, we propose, two benefits: First, by defining the goal in visualized form, the skilled performance helps the observer select learning strategies and tactics aimed at achieving the goal. Second, the performance serves as a reference standard; as skill is acquired, the observer can compare his or her performance to that of the expert and identify aspects that are missing, incorrect, or in need of improvement. The videodisc can be a powerful and cost-effective medium for demonstrating skilled performances. One illustration of this on the biology videodisc is the detailed illustration of Paul Denny's work with sea urchin DNA.

In contrast, textbook and classroom approaches do not have a good record of effectiveness in teaching complex procedures and processes. Procedures can be taught by work in well-equipped laboratories, but laboratories are expensive to equip, maintain, and staff. As a result, pre-college and college science courses have emphasized knowledge of facts and principles.

Metaphors of Commitment

Although the importance of suitable role models is generally accepted, the question of what constitutes "suitability" is not clearly understood. For example, under what conditions can a female scientist serve as a role model for a male student and vice versa? The biology videodisc introduces, describes, and "models" three levels of commitment in learning biology. The models may, however, be too contrived and simplistic to be effective. Curiously, there were few or no responses from the students concerning the metaphors of commitment provided by the fictitious role models.

Lexical Loop

Too often "knowledge" of a subject is demonstrated by verbal responses to test questions and problems. Yet practice in a discipline requires identification and discrimination among elements of a complex stimulus field (e.g., diagnosing an illness). In such cases being able to make verbal statements in answer to verbal questions is not necessarily a sufficient measure of achievement. Students must master the relationships between words, concepts, and actual, multidimensional, real-world situations. With the interactive videodisc, tests of knowledge can involve observing, manipulating, referring to, and disciminating among features of images and events. The examples from biology include cell division, gene expression, protein synthesis, and laboratory procedures. The student is not engaged in the actual activities of a scientist or a physician, but he or she is a step closer than before.

Constructive Mental Process

A current view of the way in which human memory functions may be summarized as follows. We do not record and recall experience as if our minds were tape recorders. Rather, we encode some features of an experience and combine them with some notions about how the world works in general and how that aspect of the world works in particular. For example, according to this view, we do not remember a story photographically and then replay the stored memory. Rather, we remember some aspects of a story and put these into "slots" in our general knowledge about stories (e.g., slots for the hero, heroine, villain, conflict situation, climax, resolution, ending). We combine our general knowledge with the remembered specifics to reconstruct the story [2, 3].

The features we remember and the slots we fill in order to reconstruct our understanding of a scientific concept, event, or procedure are influenced by our learning activities. When students engage in different activities during learning, they build up quite different repertoires of understanding corresponding to their different experiences. For example, if a student (a) writes

an analogy for each paragraph studied or (b) draws a picture illustrating each paragraph studied, the pattern of learning for each activity—and the kinds of questions or problems the students can respond to—is quite different. Thus, good videodisc instruction should produce learning that is qualitatively different from that of good classroom instruction because of its inherently different patterns of student activities.

Intelligent Videodisc

The limited capacity of present-day instructional computer programs to conduct a dialogue with the student and to answer questions from a flexible knowledge base appears to be a serious challenge to the computer-based education community. The interactive videodisc is likewise limited in the range of things that it can ask the student to do and in its ability to monitor the student intelligently. Sophisticated instruction that is practically available with today's computers includes simulations of such complex processes as (a) diagnosis of medical illness; (b) troubleshooting, operating, assembling, and repairing equipment; and (c) performing laboratory or other procedures. In a few research programs, artificial intelligence has been used (a) to develop "knowledge" of an academic subject, (b) to keep track of a student's performance, and (c) to engage the student in a tutorial dialogue. The intelligent computer-tutor represents an important potential of the interactive videodisc.

Executive Strategies

Several recent studies suggest that people who are good at some activity such as playing chess or learning an academic subject, have superior executive strategies for allocating their attention, time, and effort. Because these executive (sometimes called "meta-") strategies are seldom taught, it is unclear why they arise in some individuals and not in others. Students using the biology videodisc spontaneously employed a wide variety of learning strategies. One student failed despite voluminous note taking. Other students reported feeling rushed, even though

there were no time constraints. Another student read the words on the screen aloud so that she "could hear it in her head." Students sometimes generated mnemonics to help them remember key relationships. The evaluation studies reported here found that many students would persist in using ineffective learning strategies despite evidence of the lack of effect of such strategies.

In general, executive strategies have not been formally taught. Reif and Heller [4] showed that if students follow explicitly stated strategies (using a printed guide), their ability to solve physics problems improves greatly, so long as the stated strategies are before them. How can we teach students higher-level executive strategies so they will use their time and mental resources effectively? Can a combination of (a) modeling of superior strategies, (b) teaching of explicit rules, and (c) practice with feedback improve the learning and performance of students in novel, applied situations? There is no persuasive reason to believe that videodisc instruction can teach metastrategies better than classroom instruction can, but an intelligent computer/tutor can monitor student progress, offer alternative approaches, and most importantly, assist students in making wise decisions through advisement.

Transfer, Applications, and Problems

The interactive videodisc can permit a degree of flexibility in the paths a student may take in solving simulated problems. For example, in a medical diagnosis problem on videodiscs produced for Smith Kline & French Company, the student is presented with a patient and can then ask for a wide range of information (usually from menus with data stored for all selections)—not all of which is necessarily appropriate to the case. For a given problem, the computer program can identify whether the information requested was essential, peripheral, or not necessary. Similarly, when the student selects a diagnosis or treatment from a list, the computer often can interpret the accuracy and quality of the diagnosis or treatment and make comments and suggestions accordingly. These relatively simple uses of computer logic are

impressive when used to guide a student through a complex problem. The approach represents a use of the videodisc to provide instruction that cannot be given by any other means except practice with live patients under close supervision by an expert. This form of instruction is challenging and expensive to design, but the relative cost, as compared with the real-world medical setting, is low.

The biology videodisc does not capitalize on the technology in this manner, although it does include a modest laboratory simulation and some guided problem-solving experiences. If resources and demand were sufficient, biology and other science courses could use videodisc simulations to provide sophisticated laboratory experiences involving equipment that otherwise could not be made available to undergraduate students. The interactive strategies for guiding students through complex problems could be very useful in promoting the development of experimental-design and data-interpretation skills. This is especially true in such fields as genetics and molecular biology, in which interpretation involves a great deal of logical inference.

Semantic Network

Despite the concern with the limitations of purely verbal learning (the lexical loop) expressed earlier, we recognize that words are essential to help us organize material, gain mental access to our memories, and make associations across time and space. Do the visual imagery and the rich set of concrete and abstract examples provided by the videodisc enhance learning the terminology of a new discipline and promote the development of a relatively rich semantic network? Test results suggest that they may. Videodisc students significantly outperformed lecture students on a series of test items that focused on relationships between structures and processes. Further, the difference in performance was greatest with items at high cognitive levels. Perhaps students who use videodiscs are better able to run mental simulations of processes, such as cell division and protein synthesis, and therefore are better prepared to answer questions about how X is related to Y, what the order of the events is, and

Table 1
Contents of Videodisc (Phase III)

These programs occupy about one and one-half sides of a single-density videodisc. As can be seen from the frame number, materials are not necessarily arranged in the order in which they will be viewed.

Topic	Videodisc Frame Number
	Side A
Unit 0 Introduction	00001
0.1 Motion Menu Introduction	00009
0.2 How to Use This Intelligent Videodisc System	23786
0.2c Learning with This Videodisc and Your Role as a Learner	25497
Unit 1 The Cellular and Molecular Basis of Development	27205
1.1 The Basic Model of Development	27207
1.2 Cell Structure and Function	35177
1.3 The Central Role of Proteins	43505
(a) How Cells Differ	43514
(b) The Nature of Protein Molecules	43560
(c) Structural Organization of Proteins	43601
(d) Enzymes and Isozymes	45146
Lab: Electrophoresis	45187
Vocabulary Games	45449
Glossary	45505
Micrograph File	45887
Scientific Notation	46012

(continued)

where Z came from. They may have a richer semantic network, a fuller understanding of the meaning of a word, than that which can be conveyed in a lecture.

Project and Educational Objectives

Videodisc instruction is currently used primarily by the government and Fortune 500 corporations in various training and edu-

Table 1 *(Continued)*

Topic	Videodisc Frame Number
	Side B
Unit 2 The Genetic Basis for Protein Synthesis	00001
2.1 Genetic Structures	00005
2.2 Protein Synthesis: Phase I, Transcription	02711
2.3 Protein Synthesis: Phase II, Translation	03927
2.4 More About RNA and Protein Synthesis	06285
Experimental Techniques and Evidence	
(a) Experimental Techniques and Interpreting Results	06292
(b) Lab Guides	06493
(c) Experimental Evidence Relating to the Synthesis and Function of RNA	06573
Unit 3 Genetic Control of Differentiation and Development	06722
3.1 Two Models for Genetic Control	06727
3.2 Cleavage: The Egg in Control	10887
3.3 Gastrulation: Cells Move and Begin to Interact	16813
3.4 The Mystery of Organogenesis	23921
3.5 The Development Process	24955

cation programs. The WICAT "Development of Living Things" videodisc represents one of the first applications of this technology as an instructional aid for college science learning. It has implications for science teaching at all levels of instruction.

The videodisc program discussed here is the product of six years' work. The project evolved through at least three distinct developmental phases and on several parallel and intertwining tracks (described later as Hardware Configurations, Software and Instructional Strategies, and Evaluation Design). The primary focus of this paper is the results obtained in a series of comparative evaluations of student learning and attitudes.

The program material included on the videodisc is summarized in Table 1. It consists of an introduction, which explains how to use the system; three major topics (The Cellular and Molecular Basis of Development, The Genetic Basis for Protein

Synthesis, and Genetic Control of Differentiation and Development); and some special features, such as a glossary, vocabulary games, laboratory demonstration, and scientific notation file. The videodisc addresses such issues as:

- How DNA serves as the blueprint for the development of living organisms
- How the chemical and physical properties of DNA permit self-replication and RNA synthesis
- How mitotic cell division takes place
- How proteins are synthesized according to the DNA blueprint through the coordinated actions of ribosomes, messenger RNA, transfer RNA, and activating enzymes
- How cell differentiation occurs in developing organisms.

The fully developed prototype videodisc contains material at upper-division and graduate levels of instruction. It aims to teach (a) conversational (declarative) knowledge, (b) procedural knowledge and skills, and (c) knowledge of causal relationships.

Project Description

Hardware Configurations

After preliminary trials with several hardware and language configurations, a microprocessor system was developed by WICAT Systems, Inc. In Phase I the WICAT microprocessor was combined with a Magnavox manual player, and in Phase II and Phase III it was combined with a DiscoVision Industrial/Educational player, which proved to be faster and more reliable than players designed for home use. A videodisc interface board connected the computer and videodisc player.

The fully developed prototype version of the "intelligent" (interactive computer-based) videodisc system is shown in Figure 1. The components include (a) a powerful microcomputer, (b) an industrial/educational videodisc player, (c) a videoscreen, (d) a computer screen, and (e) a keyboard. The computer program for the computer–videodisc interaction is contained on a floppy (flexible magnetic) disc. Before the start of a session the com-

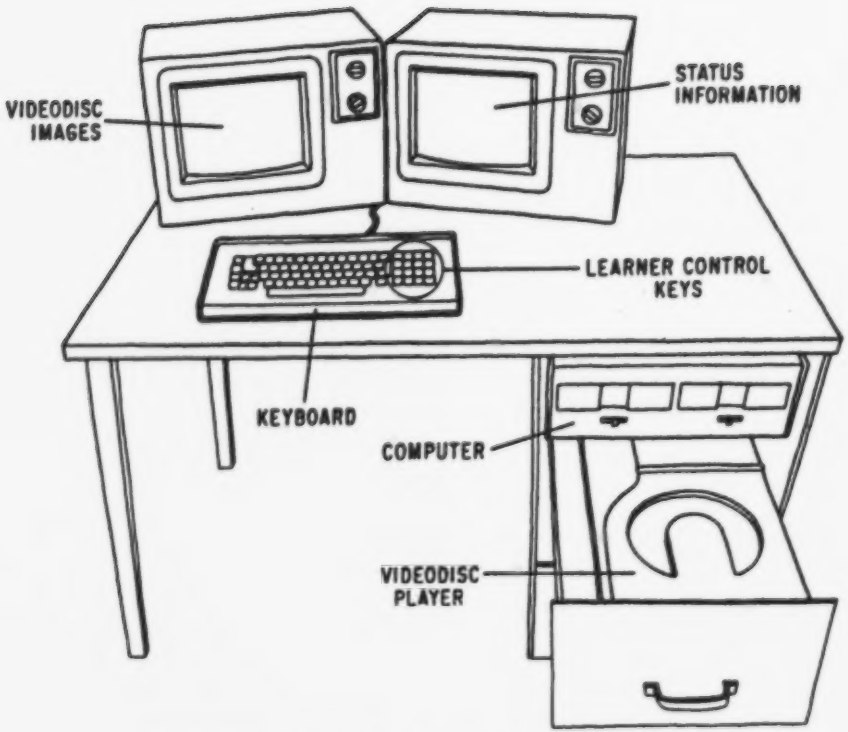

FIGURE 1. The prototype intelligent videodisc system.

puter program is transferred from the floppy disc to the main random access memory of the computer. The program for Phase III requires about 256K bytes of memory.

Two screens were used—a color television monitor for information stored on the videodisc and a black-and-white monitor for the computer display. The question of whether to use one screen or two was not easily resolved. Using only one screen would have required that all computer text be superimposed on the video screen. Because of the low resolution of U.S. television, this would have limited both the quality and quantity of computer-generated text. It also would have complicated the management of electronic signals from the computer. Not only can more information be supplied to the student simultaneously with two screens, but the student also learns to look to each screen for different kinds of information. The principle negative consideration is the additional cost of the second screen. In the prototype study this was not a critical factor.

The DiscoVision optical videodisc player provided many features, such as random access to frames, freeze frame, variable-speed motion, and large storage capacity. Computer control permitted frame access based on complex algorithms or on learner choice. This permitted branching pathways through the material based on the student's background knowledge and mastery of previously presented information. The computer was used to keep records of student responses and to provide answer judging, answer analysis, help, additional (higher- or lower-level) information, and so on.

The keyboard (Fig. 2) contained 16 learner-control keys, divided into three groups: eight keys to control the videodisc, four keys to select a particular domain on the screen (right, left, up, down), and four keys to control the motion sequences (PLAY, FAST, SLOW, and STOP). Another three keys allowed the student to control overall progress through the disc:

- With NEXT the student moved along the default path chosen by the computer.
- With MENU the student moved to other locations.
- With JUMP the student could go back and forth between

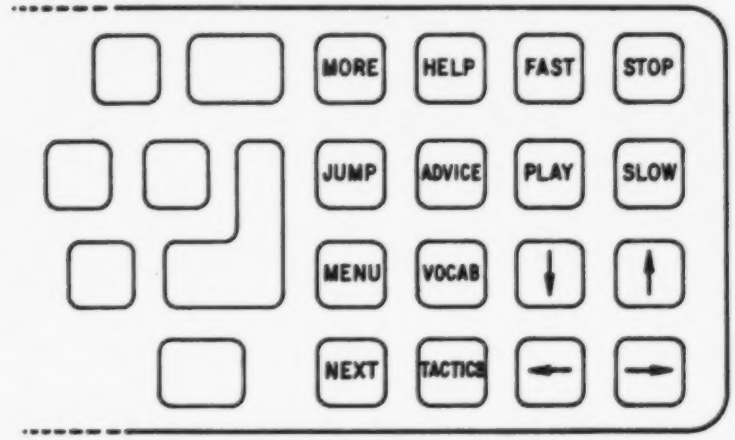

FIGURE 2. Intelligent videodisc keyboard.

two locations (if, for example, the student wanted to compare transcription and translation by moving back and forth between them).

There were also five special function keys:

- ADVICE gave general status information about what the student had accomplished and provided generalized comments on strategies and tactics.
- TACTICS allowed the student to review specific parts of a lesson, such as the rules, motion sequences, micrographs, or practice problems.
- MORE provided more specific and sophisticated information about a subject.
- VOCAB provided access to the interactive glossary.
- HELP provided hints and additional information to aid the student with practice items.

Figure 3 illustrates the information flow in the computer-based videodisc system. In a sense, the student and the computer regulated information flow cooperatively. The student could be asked a question by text on the videoscreen, and the typed answer could be interpreted by the computer, which would then give

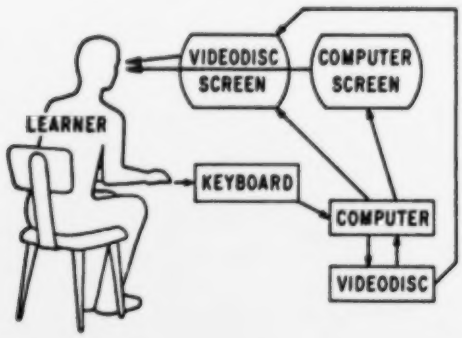

FIGURE 3. Information flow.

feedback and corrective comment. If needed, branching to corrective instruction could take place under either the student's direction or the control of the computer program. The keys and their functions were selected on the basis of research on learning processes and student control of learning, in combination with the capabilities of the computer–videodisc system. In particular, the TICCIT project [5] provided much of the evidence for the decisions.

Software and Instructional Strategies

The authoring software used in this project was the Courseware Design System (CDS) developed by WICAT Systems, Inc. Documentation on CDS and information about how it may be used to facilitate authoring is available from WICAT Systems. The authoring system and the student registration package were developed independently of this project.

The instructional units used a rule–example–practice design with color-coding of frames to signify the type of information being presented. The student was led through a series of discussion frames (blue background) that carried the main thought. These were interspersed with rust-colored rule (general principle) frames, pictorial or black example frames, green practice-problem frames, and gray answer frames. Yellow frames provided orientation and status summaries. The moving sequences were derived from the film library of McGraw-Hill. In-

structional materials were generated by WICAT in collaboration with professors William S. Bradshaw, Duane E. Jeffery, and James L. Farmer, from the zoology department of Brigham Young University.

The instructional design was developed in three phases.

Phase I. The initial version was prepared for a manual videodisc player that was not computer-controlled. The student could proceed through the disc only in linear fashion, as if it were a one-way text enriched with motion sequences, slides, and practice items. One could go forward and backward with fast, normal, or slow motion and could search for a specific frame but always with the requirement of moving linearly, as though the program were on tape. Although more flexible than tape, this requirement was nonetheless cumbersome, especially when compared with later computer-controlled versions. The instructional approach included the following:

- *Rule Statements.* Key principles and relationships are stated succinctly in the form of a rule (Fig. 4). A rule usually is stated in less than 20 words on a single frame of a videodisc.
- *Examples.* Examples of concepts and the application of principles are provided explicitly to help the student map out the domain of a concept or relationship. Examples are provided by still frames that are usually like illustrated pages of a textbook. (*Note:* An important distinction between still frames and textbook pages is that a still frame usually is organized to express a single complete idea.)
- *Discussion.* This is an extended sequence of still frames that elaborates a principle, a relationship, or a process. Discussion frames are more discursive than rule frames.
- *Practice.* Practice frames give students an opportunity to test themselves and receive feedback that both informs them of the answer the authors think is correct and often elaborates on why the answer is correct or why the question is interesting.
- *Motion Sequences.* Beautiful and compelling motion sequences taken from McGraw-Hill instructional biology films illustrate important processes (e.g., cell division, DNA rep-

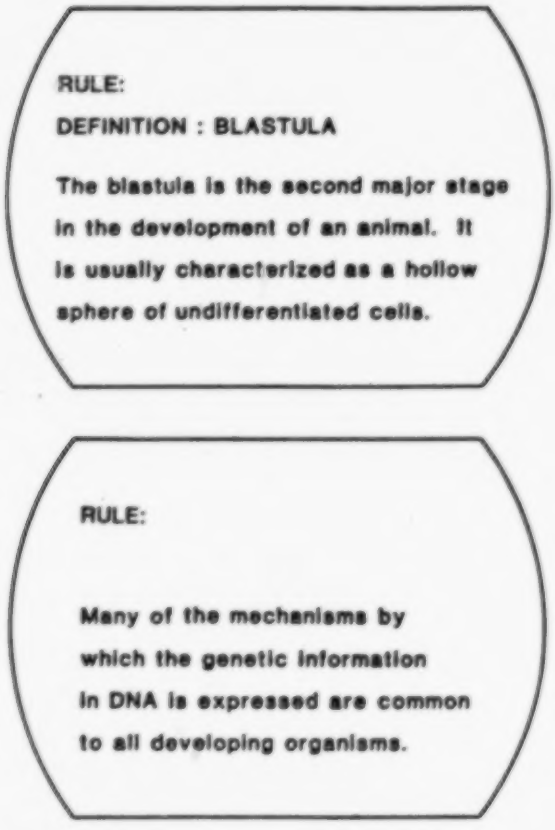
RULE:
DEFINITION : BLASTULA
The blastula is the second major stage in the development of an animal. It is usually characterized as a hollow sphere of undifferentiated cells.
RULE:
Many of the mechanisms by which the genetic information in DNA is expressed are common to all developing organisms.

FIGURE 4. Example rules.

lication, protein synthesis) and laboratory procedures. Students were encouraged to take notes and to write the answers to practice items in a notebook.

Phase II. Next, the videodisc was put under computer control so that one could "move around" on the disc in a nonlinear fashion. As a result, the following features were added:

- *Menus.* Menus or hierarchical tables of contents were provided for the parts, units, and lessons so that a student could move to selected positions of a disc.

- *Branching.* The computer would automatically branch to a particular portion of the program as a consequence of an answer given to a practice item by the student.
- *Answer Judging.* The computer program for Phase II could carry out simple answer judging (e.g., discriminating between correct and incorrect, true–false, and multiple-choice answers) and provide differential feedback for different answers.
- *Scoring.* Student scores on practice items for a given unit of instruction were kept in Phase II.
- *Status.* The status function told the student which units of instruction had been engaged, which completed, and which remain to be studied.

Phase III. Finally, simulations, word games, interactive glossary, enhanced branching, scoring, answer judging, and status were added. Whereas Phase I had 650 still frames (the equivalent of about 130 pages of text), Phase III had four times that number (about 500 pages of text).

- *Simulations.* The prototype "intelligent" videodisc includes simulations of laboratory experiments.
- *Word Games.* A word game, Biomastery, was introduced in Phase III to aid the acquisition of terminology.
- *Interactive Glossary.* The prototype Phase III glossary includes definitions and, when possible, photomicrographs, diagrams, line drawings, and other pictures to clarify the meaning of terms and concepts.
- *Orientation.* The interactive biology disc has a section that dramatizes explicitly some goals students may have in taking a required college biology course. The purpose is to explain to the students how they can meet their goals and, it is hoped, to encourage and interest the students in becoming more committed and involved with the understanding of biology. This explicit recognition of the emotional and motivational basis of academic effort is an interesting element in this prototype.
- *Enhanced Answer Judging.* In the Phase III version of the disc the student may type in words (e.g., zygote) on the computer screen as an answer to a practice item. The com-

puter program can interpret the answer and tolerate a degree of misspelling when the designers permit this. In multiple-word answers the program searches for key words and judges the quality of an answer by the degree of match to the authors' key-word list.

Evaluation Design

In examining a prototype of a new medium of instruction, many questions might be asked. However, the investigators limited their evaluations to the following. Students using the intelligent videodisc were compared with lecture-taught students of comparable background. Both groups took the same pre- and postexaminations. The students were also asked various questions regarding ease of learning, learning time, the instructional system, and how their feelings about biology had changed as a result of their experiences. In addition to structured questionnaires, students were asked to write open-ended essays on their experiences and were interviewed subsequently by the researchers. Students' interactions with the videodisc were recorded by both computer and human observers. The videodisc research was conducted in three major phases, in parallel with the development of the disc.

In all three phases the videodisc programs were the principal source of instruction for the students. No supplemental lectures or workbooks were provided on these topics. In the early studies, students received no credit for learning the material contained in the programs, and little or no assistance was available from the staff. In later comparative analyses the videodisc programs were presented as an integral part of the biology courses in which students were enrolled (in these cases, textbooks were available to the students using the videodisc).

Methods and Results

Phase I: Manual Videodisc

Three formative evaluation studies of the manual videodisc were conducted during Phase I (Table 2). These three studies are de-

Table 2
Phase I Research Groups

Formative evaluations of the manually operated (noncomputerized) videodisc were conducted with graduates (G) and undergraduates (U) at Brigham Young University (BYU) and Utah Technical College (UTC); M = male, F = female.

		Student Characteristics						
Study	Institution	U	G	M	F	Mean Age	Total Number Students	Student Major
Instructional analysis	BYU	35	0	18	17	20.5	35	Biology (10) Non-biology (25)
Learning strategies analysis	UTC	7	0	1	6	24.3	7	Life science Nursing
Features analysis	BYU	22	16	18	20	24.5	38	Biology (22) Media (16)

scribed below. Detailed descriptions of the evaluation procedures and instruments may be obtained from the authors.

Instructional Analysis. The study focused on student achievement and instructional process variables when the manual videodisc was used. The subjects consisted of 35 undergraduate students—17 females and 18 males—majoring in biological (n = 10) and nonbiological (n = 25) sciences at Brigham Young University (BYU). The average age was 20.5 years. Thirty-five percent were upper-division students and 54 percent expressed a strong interest in biology.

Alternate-form pre- and posttests were given for each lesson. Statistically significant pre–post gains were made on each unit. Gains by unit (average posttest score minus average pretest score) were as follows: Unit 1, 16 percent; Unit 2, 34 percent; and Unit 3, 30 percent. Unit 1, which includes a review of basic biological principles, was the easiest, according to pretest scores.

One of the claims for computer-based instruction is that it allows for wide variations in the time it takes different students to master the material. Hence, the time per unit spent by stu-

Table 3
Time Spent in Each Instructional Unit
(Phase I, $N = 38$)

Time spent in each instructional unit was determined for 38 BYU students in the instructional analysis group using the Phase I manual videodisc.

Unit	1	2	3
Average time in unit (minutes)	52	69	65
Standard deviation (minutes)	12	20	15
Range (minutes)	25–83	35–130	38–108
Ratio (max/min)	3.3	3.7	2.8

dents is of interest. A wide range in completion times was observed (Table 3).

To assess how the students used the various options available to them, an observer, using a microcomputer, recorded the students' frequency and duration of use of each type of instructional frame and videodisc key. The time spent per rule frame decreased as students proceeded through the three instructional units. Students also spent successively less time on answer frames. However, they spent longer times on the practice frames for the more difficult concepts in Units 2 and 3, as compared with those in Unit 1.

Although the videodisc provided the opportunity for a moderate level of interactive and learner-controlled instruction, most students proceeded in a linear, step-by-step fashion. A substantial number of students did not use many of the videodisc control keys, and three students did not use any. Out of 35 students, 23 used the still reverse key, 22 used the search key, 19 used the index and fast-forward keys, 18 used the slow-motion key, and 11 used the key for reverse motion.

Learning Strategies Analysis. This evaluation was conducted to probe in greater depth the types of instructional and learning strategies that students employed with a manual videodisc. The sample consisted of seven life science and nursing students at Utah Technical College (UTC). Six of the students were female; the average age was 24.3 years. Four of the seven expressed a

high interest in biology. These students were not as academically talented, prepared, or confident as the students from BYU.

As students worked through the videodisc, they were asked to verbalize their decisions for using the various videodisc keys and features. Observers used a paper-and-pencil observation instrument to record the use of videodisc keys that departed from the standard lesson flow and to record the reasons the keys were used. Students were also asked to identify any areas of the lessons that were difficult to understand. After each videodisc lesson the participants completed a rating form concerning the instructional characteristics of the lessons and the learning strategies they were using. Short interviews were conducted for each lesson based on the observational records and rating forms. The students also completed identical pre- and posttests on the lesson material.

It is uncertain whether the strategies used by these students, under the close scrutiny of the researchers, were the same as those that would have been used if the students were working unobserved. Nonetheless, this study provided some useful insights into the lesson design, especially its suitability for underprepared students. The UTC students had the greatest difficulties when the posttest items did not resemble closely the practice and self-test items in the lessons. This suggests that they had not integrated the material so that they could use it effectively in responding to novel questions. Because the ability to respond to novel questions is a measure of "understanding," it appeared that the UTC students needed both additional and different activities and experiences to achieve understanding. This study also helped define the strategy patterns described in Phase II.

Features Analysis. The feature analysis sample consisted of 22 upper-division biology students and 16 graduate students in instructional media courses at BYU. Twenty students were female and 18 were male; the average age was 24.5 years. Fifty percent of the students had a strong interest in biology. The study focused on student use of and attitudes toward the various orientation, graphic, and format features of the manual videodisc. Questions concerned the things students liked, disliked, or felt needed improvement. Students in the first two studies also com-

Table 4
Manual Videodisc: Likes and Dislikes
(Phase I)

This summary includes responses to both structured surveys and open-ended questions. Responses are listed in approximate order of frequency of response. The three groups are (1) features analysis (N = 38), (2) instructional analysis (N = 35), and (3) learning strategies analysis (N = 7).

Comment	Group 1	2	3
Things liked			
Integrated use of motion and still frames	×	×	×
Ability of lessons to hold attention and interest	×	×	×
Clear lesson organization and format, one idea per frame	×	×	×
Practice, review, and answer feedback features	×	×	×
Control of the process of learning; ability to learn at own rate	×	×	
The in-depth scope of content coverage		×	×
Use of filmed experiments and demonstrations	×		
Effective use of color coding of frames	×		
Ease of use of the videodisc keys	×		
Things disliked or needing improvement			
Videodisc image jitter and blur	×	×	×
Clarify explanations of videodisc keys and symbols	×	×	×
Provide more practice items, examples, and reviews	×	×	×
Poor color clarity, sharpness, and contrast	×	×	
Videodisc keys stick	×	×	
Provide clearer definitions and explanations for some concepts		×	×
Provide more motion sequences		×	×
Provide access to a tutor or additional references for further study		×	
Use earphones to reduce distractions		×	
Provide audio for the still frames	×		
Provide a computer hookup for the videodisc	×		
Reduce number of videodisc symbols per frame	×		
Put the still and play keys closer to each other	×		
Include a stop key to freeze a motion segment on a frame	×		
Have shorter lessons			×
Provide additional references for in-depth learning			×
Provide a "place marker" for efficient search and return to a videodisc frame			×

pleted questionnaires and responded to open-ended questions concerning their likes and dislikes. The results from all three groups are summarized in Table 4. In general, students said they liked the individual pace and the illustrations provided by the videodisc. They wanted more motion sequences and practice opportunities, and they disliked various technical problems and constraints.

Phase II: Lecture–Videodisc Comparisons with Enhanced Videodisc

The computer-enhanced Phase II videodisc was compared with high-quality classroom lectures with respect to student learning and attitudes. The computer enhancements included computer control of all videodisc functions, interactive practice and feedback sequences, student status information on performance scores, and menu selection of alternative learning and review tactics. Twenty-five students from an introductory biology course at BYU volunteered to use the computer-enhanced videodisc. The remaining 60 students in the class constituted the lecture group. The investigators would have preferred to randomize students into treatment groups, but this was not done when the teacher preempted this possibility by asking for volunteers (information was collected on a pretreatment questionnaire and a pretest to assess pretreatment equivalence between groups, as described below).

Content. A common instructional unit was selected for the comparative evaluation. The topics were DNA structure and function and the transcription and translation phases of protein synthesis. This unit was chosen because of the overlap between the content and objectives of the videodisc instructional unit, the classroom lecture topics, the class syllabus, and the textbook assigned for the course. Each classroom instructor was given a list of the videodisc objectives and the posttest before lecturing on these topics.

Lecture Group. The students in the lecture group received their instruction in the usual lecture mode. Classroom observations were conducted during the lectures. The observers noted the

content coverage, presentation characteristics, number of practice items presented, and questions raised by the class. The observers also recorded the total presentation time for the classroom lectures. Follow-up interviews were conducted with the instructors.

Videodisc Group. Videodisc students did not attend class during lectures on topics in the videodisc unit. They used the videodisc as an alternative to the lecture. The videodisc students were given an intrpduction to the videodisc system and control keys. They were then given a free-play period of 15 minutes to try out each key. During the introduction and free-play period the students were not permitted to study the instructional material. After the free exploration time the students were asked to start the experimental unit, which they completed in one sitting. As students worked through the instruction they were asked to report aloud when they used the videodisc control keys (e.g., slow motion, reverse, jump, rule review) to depart from the normal lesson flow and to indicate their reasons for using the keys. An observer recorded the videodisc keys used and the students' reasons for using them. The observer also recorded the time the students needed to complete the instructional unit on the disc. Follow-up interviews were conducted with the videodisc students.

Experimental Design. A pre/postretention design was used. Students in the lecture and videodisc groups received a prequestionnaire, a pretest, the designated treatment, a posttest (one day after instruction), and a retention test (one week after the posttest). The videodisc group also completed a postquestionnaire (these results are discussed in a later section on attitudes). The dependent. variables were student achievement, presentation time and outside study time, and (with the videodisc group only) learning strategies. Care was taken to ensure that the videodisc and lecture were comparable in terms of content and objectives and that the evaluation procedures and tests were fair to both systems.

Prequestionnaire. The prequestionnaire requested factual information on student age, sex, class standing, high school and col-

lege GPA, and college major; it also assessed pretreatment levels of interest, knowledge, confidence in, and attention to both biology and their college major. Students were also asked to indicate which of four role commitment classifications best described them: (1) a practical learner, (2) an interested lay person, (3) a future specialist, or (4) a future research scientist.

Test Characteristics. The same test was given as a pretest, a posttest, and a retention test. The test consisted of 58 objective items (20 multiple choice, 29 matching items, and 9 true–false), 22 short-answer items, and two short-essay items. About three-fourths of the items were fact-recall. The test was representative of the domain of knowledge presented in the videodisc, in the class syllabus, and in the textbook chapters. The Kuder–Richardson KR-20 reliability for the test with each experimental group is presented in Table 5. Because reliabilities of .75 or higher are considered acceptable, the data indicate high and very acceptable reliabilities for pre-, post-, and retention tests. The reliability of the test would be slightly reduced by the ipsitive nature of four of the test items.

A test key was used for scoring both objective and short-answer test items. Blind scoring procedures were used for the short-answer items. The blind inter-rater reliability was .98 to .99 for the short-answer questions, and .96 and .99 for the two

Table 5
Test Reliability
(Phases II and III)

Test reliability was determined by the Kuder–Richardson KR-20 method. The same test was given for the three Phase I experimental groups and as pre-, post-, and retention test in Phase II and Phase III studies.

	Pre	Post	Retention
Lecture			
Reliability KR-20	0.79	0.91	0.99
Standard error	3.28	3.00	2.00
Videodisc			
Reliability KR-20	0.74	0.87	0.99
Standard error	3.33	2.85	1.83

short-essay questions. In repeat scoring by different persons, 70 percent of the essay scores were identical, 28 percent were within one point, and 2 percent were within two points.

Pretreatment Equivalence Between Groups. Results from the prequestionnaire were analyzed for pretreatment differences between groups. A chi-square test was computed for categorical variables. None of the values exceeded 1.5. These results show that there were no significant differences between groups on age, sex, college class, high school and college GPA, and their self-reported interest in biology, attention in biology, or their role commitments. Thus, across these variables the lecture group and the videodisc group can be considered comparable. A t-test on the pretest scores indicated no significant differences between groups ($t(1.48) = 0.62$). The groups are thus comparable on pre-achievement scores. This is true whether one compares the videodisc group with the 60 lecture students who participated in the experiment or with the subset of 24 lecture students who completed all tests (see below).

Student Achievement. Twenty-four lecture students completed the pretest, posttest, and retention test. Their performance is compared with the videodisc group ($N = 25$) in Table 6. The results are presented for objective, open-ended, and total test scores. The scores were similar for the videodisc and lecture groups on the pretest. The videodisc group scored higher than the lecture group on all parts of the post- and retention tests. The videodisc group also scored higher on prepost and preretention test comparisons. These differences between groups are not significant on the objective subtest scores but are highly significant for the open-ended subtest and total scores.

Learning Time. Table 7 summarizes the presentation time and outside study time (as determined by student self-reports) for the lecture and videodisc groups, reporting both the median and the mean. The study time distributions for both groups were skewed, since several students in both experimental and control groups spent many hours of outside study time. Sixty percent of

Table 6
Comparative Student Achievement
(Phase II)

Achievement was determined for students in an introductory biology class at Brigham Young University. Twenty-five student volunteers studied selected topics on the computer-enhanced videodisc, and the remainder received lectures on these topics. Pretest, posttest (given one day after instruction), and retention test (given one week later) scores are shown and gain scores are calculated.

	Videodisc (N = 25)		Lecture (N = 24)		t (1.48)
	Mean Score (Standard Deviation)				
Pretest					
Objective	19.9	(7.8)	20.7	(7.5)	.37
Open-ended	1.5	(2.8)	2.4	(5.8)	.66
Total	21.4	(9.4)	23.1	(12.6)	.62
Posttest					
Objective	39.5	(8.7)	36.6	(10.7)	1.04
Short answer	25.9	(13.1)	15.0	(11.7)	3.07*
Total	65.4	(18.1)	51.6	(21.4)	2.21*
Retention test					
Objective	40.4	(9.7)	38.0	(8.3)	.89
Short answer	24.2	(13.9)	17.8	(12.0)	1.74
Total	64.6	(21.9)	55.8	(19.2)	1.56
	Gain (Standard Deviation)				
Pretest–posttest					
Objective	19.6	(15.6)	15.9	(9.3)	1.97
Open-ended	23.4	(11.0)	12.8	(10.7)	3.42*
Total	46.5	(15.0)	28.7	(18.9)	3.04*
Pretest–retention test gain					
Objective	20.5	(7.3)	17.3	(8.1)	1.42
Open-ended	22.7	(12.8)	15.4	(10.7)	2.17*
Total	43.2	(18.1)	32.7	(16.5)	2.20*

*alpha <.05; t (.05) = 2.02

Table 7
Comparative Learning Time (minutes)
(Phase II)

Learning time was assessed for BYU students exposed to videodisc and lecture presentations. $\bar{X}$ = mean, Med = median, SD = standard deviation, N = number of students.

Group	Statistic	Presentation Time	Outside Study Time	Total Learning Time
Videodisc	$\bar{X}$	73.2	51.0	124.2
	Med	80.0	30.0	105.5
	SD	12.1	52.7	51.1
	N	24	24	24
Classroom	$\bar{X}$	68.5	113.9	182.4
	Med	68.5	70.0	138.5
	SD	0.0	97.1	97.1
	N	24	18	18*

*Six classroom students failed to indicate the amount of outside study time.

the videodisc group and 50 percent of the classroom lecture group studied less than one-half hour outside of the presentation. Twelve percent of the videodisc group and 25 percent of the lecture group spent two or more hours in outside study.

Overall, the videodisc group spent less time studying than the lecture group, yet they reported greater levels of confidence in their knowledge. The difference was 32 percent (58.2 minutes) based on the mean or 24 percent (33 minutes) based on the median. In interpreting the results, it should be remembered that the videodisc subjects were volunteers.

Learning Strategies. The ways in which videodisc students used the various options provided to them were examined. Five major patterns were observed. The first was a linear, step-by-step pattern with no deviations. Three students used this strategy.

In the second pattern the students went through the lesson rapidly, skipping material they thought they already understood. Two students used this fast-skipping strategy.

The third pattern involved initial viewing of the motion sequences for a general overview and then stopping and reviewing the motion sequences to take notes the second time through. Key points in the motion sequences or rule frames were noted before progressing. Seven students followed this strategy.

The fourth pattern involved a careful review of the motion sequences and still frames during the initial pass through a lesson. Seven students used this incremental review strategy.

The fifth pattern involved a moderately linear path through the motion sequences, rules, examples, and discussion frames. However, when these students had difficulty with the practice exercises, they would review the still frames or motion sequences for information needed for the practice exercises. Six students used this test/review strategy. When these students discovered that the answer and feedback frames contained the information about each practice item (making return to the lesson unnecessary in most cases), they modified their review strategies, examining the answer and feedback frames for a practice item that was giving them trouble.

The most frequently used learner control keys were the key for stopping motion sequences, the key for reviewing the immediately preceding frames, the key for jumping to the beginning of a motion sequence, and the jump key that allowed for motion review, rule review, or practice review. The jump key also provided a place marker in the lesson for returning to the point of departure. The slow-motion and fast-motion keys and the forward preview keys were the least frequently used learner control keys. The above results show that learner control keys were used primarily for review, rather than for preview or motion speed changes.

Phase III: Lecture–Videodisc Comparisons with the Fully Developed "Intelligent" Videodisc Prototype

The Phase III evaluation focused on the fully developed "intelligent" Phase III videodisc described earlier. The programs on this disc were about twice the size of the Phase II programs and included many special features. Two class sections of Introduc-

tory Biology were selected for participation in the evaluation—one section from Brigham Young University (BYU) and one section from Brookhaven Community College (BCC) in Dallas, Texas. The students in each class were randomly assigned to videodisc and classroom lecture groups. At BYU there were 73 students in the lecture group and 24 students in the videodisc group. At BCC there were 25 lecture students and 28 videodisc students.

Content, Methods, and Instruments. Phase III focused on the same unit of instruction (DNA structure and function, protein synthesis) as that studied in Phase II. The observational data from both BYU and BCC classroom groups indicated excellent content coverage of the selected topics by the lecturers. Classroom observations were keyed directly to each item on the posttest. Phase III also employed the same research methods and used precisely the same test and questionnaires (except that no retention test was administered).

Presentation Characteristics. The BYU classroom instructor lectured for three 50-minute periods on the selected content areas. The instructor provided the students with handouts covering 19 objectives within the selected unit. To teach the selected topics the instructor used overhead transparencies, blackboard illustrations, references to pages of the textbook, and a film. The instructor presented five to nine practice items per class hour and answered an average of 14 questions from students.

The BCC (junior college) classroom instructor also lectured for three 50-minute periods on the selected content areas, using the same visual media and references. The instructor employed a unison class response method for the practice items. All student questions were answered.

The videodisc presentation averaged just over two hours during which the students saw about 230 still frames and four one-minute motion sequences. The videodisc lesson included 7 objective frames, 52 rule frames, 42 discussion and example frames, 58 practice frames, 58 feedback frames, and 15 additional information frames. Students were able to use the intelligent videodisc controls to select which things they would like to

Table 8
Comparative Student Achievement
(Phase III)

Achievement was determined for two groups of students at two different sites: Brigham Young University (BYU) in Provo, Utah, and Brookhaven Community College (BCC) in Dallas, Texas. Students were randomly assigned to either classroom (Lect.) or videodisc (Vdsc.) groups. The latter used the fully developed Phase III prototype disc. Presented are the number of students (*N*), mean score (M), and standard deviation (SD).

		Site					
		BCC			BYU		
Treatment		Lect.	Vdsc.	t	Lect.	Vdsc.	t
Pretest	*N*	25	28		73	24	
Objective	M	22.1	20.9	.70	20.0	20.4	.27
	SD	5.9	6.9		5.6	8.3	
Short answer	M	1.6	1.6	.00	2.0	2.5	.67
	SD	2.6	2.9		2.5	4.8	
Total	M	23.7	22.5	.56	22.0	22.9	.46
	SD	7.0	8.7		6.4	12.8	
Posttest		25	28		73	24	
Objective	M	36.5	43.0	2.94*	47.1	50.0	2.00*
	SD	7.4	8.5		6.5	4.9	
Short answer	M	15.6	21.4	2.10*	30.5	35.6	2.72*
	SD	10.0	9.9		8.7	5.1	
Total	M	52.1	64.0	2.54*	77.4	85.7	2.65*
	SD	16.6	17.2		14.5	9.3	

*alpha < .05; t (52 df) = 2.0

study, to enter their answers for the practice items, and to review any frame, motion sequence, or major lesson segment. Pointers were displayed on each menu to allow the student to move in and out of each lesson segment without becoming lost.

Student Achievement. Table 8 summarizes mean pre- and posttest scores for the BYU and BCC comprisons. There were no significant differences between groups on the pretest. However,

significant differences in favor of the videodisc groups were found on all parts of the posttest. *The videodisc groups consistently outperformed the associated classroom lecture groups.*

Learning Time. Table 9 compares the lecture and videodisc groups on the variables of presentation time, outside study time, and total learning time. Significantly less learning time was required for the two videodisc groups. *These figures represent 30 to 40 percent time savings with videodisc instruction.*

Learning Productivity. Table 10 summarizes the learning productivities of the videodisc and classroom lecture groups. Learning productivity [6, 7] is defined as the average student achievement gains (points gained on pre/post achievement tests) divided by the average total learning time (in hours) expended to achieve those gains. The productivity ratios for the classroom groups were, respectively, 4.45 for BCC and 8.02 for BYU. The productivity ratios for the videodisc groups were, respectively,

Table 9
Comparative Learning Time (minutes)
(Phase III)

Learning time was assessed for BYU and BCC students using the fully developed Phase III disc and for students receiving lectures.

Study Site	BCC			BYU		
Treatment Group	Lect.	Vdsc.	t	Lect.	Vdsc.	t
Presentation time						
M	150.0	122.8	2.28*	150.0	137.6	1.84
SD	0.0	30.3		0.0	29.2	
Outside study time						
M	232.5	138.0	2.24*	265.3	96.4	6.27*
SD	107.6	94.4		85.6	81.1	
Total learning time						
M	382.5	260.8	3.57*	415.3	234.0	6.26
SD	107.6	113.0		85.6	98.0	
N	25	28		73	24	

*alpha <.05; t (52 df) = 2.0

Table 10
Learning Productivity Comparisons
(Phase III)

Comparisons are made for the BYU and BCC groups in Phase III.

	BCC		BYU	
	Lect.	Vdsc.	Lect.	Vdsc.
Achievement gain (pts)	28.4	41.5	55.4	62.8
Learning time (hr)	6.38	4.35	6.91	3.90
Learning system productivity ratio (gain/time)	4.45	9.54	8.02	16.1

9.54 for BCC and 16.1 for BYU. *These productivity ratios show a twofold increase for videodisc instruction as compared with traditional classroom instruction.*

Discussion

Comments by Fisher and Lipson

The scope of this project is impressive, with respect to both the hardware and software production and the rather extensive evaluations that were performed. How meaningful are the latter? The studies share the common problem that the developers of the instruction are also the evaluators of its effectiveness. The situation is further complicated in this case because all three researchers (and one of us) are employees of WICAT, Inc., a firm that markets videodisc hardware and software. The possibility of some inadvertent influence on outcomes because of these vested interests must be acknowledged.

The aura created by a glamorous new electronic medium also could distort outcomes. That is, would the videodisc be as motivational and effective (compared with lectures) if the videodisc were old hat and lecturing was a new discovery?

However, there are various reasons for suspecting that the findings reported here are meaningful. First, the evaluators are schooled in the tradition of research scientists and have estab-

lished records in instructional evaluation before their affiliation with WICAT. Second, because these studies were undertaken soon after the videodisc came into existence, it was to WICAT's distinct advantage to be rigorously objective, so as to learn as much as possible about how to produce good videodisc hardware and software. Third, most formative evaluations in industry necessarily use in-house evaluation personnel. Fourth, the replication of findings by different groups may diffuse any potential bias; the biology videodisc is available to the public, and independent evaluation is now underway. Finally, the findings are in agreement with the extensive literature on individualized instruction, both with respect to learning gains and time savings. Increased student confidence is also commonly reported in autotutorial courses. The values of imagery and experiential learning (direct and vicarious) are also widely touted, although perhaps less documented by hard data.

The studies reported here suggest that the videodisc is a potentially more powerful instructional device than any that has preceded it. Other studies by other researchers are sorely needed to assess the validity of this conclusion. In the meantime the readers will have to weigh the evidence and form their own conclusions.

Next Stage of Development

A more advanced interactive videodisc will require more sophisticated programs, including implementation of artificial intelligence concepts and more memory. The programs will probably include (a) an explicit general model of a learner that is modified to fit a particular student as the student interacts with the instruction; (b) an extensive representation of the subject being taught; and (c) rules for interacting with the learning as data source, a tool, a teacher, a coach, and a tutor (among others), possibly with varying levels of expectation appropriate to the student's goals. The program should be capable of detecting errors, analyzing patterns of errors, and perceiving various other response patterns. It may draw tentative conclusions as to the causes of errors, modify the material presented to the student on

the basis of this analysis, and engage the student in a dialogue that, based on the model of the student, has a good probability of helping the student to overcome his or her errors and misconceptions. We believe that the success of this prototype should only spur us on to the next challenge—that of increasing the intelligence of the system. (At the same time we recognize that increasing computer intelligence is liable to produce negative as well as positive social effects, many of which may be nontrivial [8].)

To use increasing computer intelligence wisely for educational purposes, we will have to learn much more about how and why people learn. Prototype experiences like this one help us think about the learning process from a new perspective. In order to develop the rich theoretical model we envision, the sciences currently gathered under the title of cognitive science will, in our judgment, have to be expanded to include research into (a) emotional factors in learning, (b) social factors in learning, (c) personality factors in learning, and (d) other related areas.

From the studies described here it appears that students do respond favorably to an interactive videodisc program that (a) keeps their attention; (b) uses clear, well-organized text; and (c) is rich in examples (including pictorial ones), practice with feedback, and simulation of complex procedures. It also appears that this instructional design may enhance student learning significantly as compared with classroom lectures. Some considerations counterbalance this apparent increase in learning productivity, however, such as (a) the high cost of videodisc production, (b) the complex and cumbersome nature of the processes involved in creating instructional programs on videodisc, and (c) the difficulty of editing existing videodisc programs.

Videodisc costs are not likely to decline as dramatically as computer costs have. For these reasons we suspect that despite promising potential gains in various applications, the videodisc will be most successful in applications that:

- Capitalize on the relatively low cost and rapid retrieval capabilities of the disc for visual images (as in storing 108,000 slides per disc)

- Provide a useful service to a large market (such as an illustrated, automated encyclopedia and dictionary), so as to justify and amortize the costs
- Provide a qualitatively different kind of instruction that cannot be provided as well in any other way (as in guiding students through complex problem-solving paths using simulations and multiple interactive strategies).

Summary

The videodisc ability to supply a huge reservoir (108,000) of photographically realistic images at relatively low cost, together with the logic of computers, permits the development of effective simulations of laboratory procedures, experiments, and biological processes. If exploited, this could enhance science curricula dramatically. But cost and other constraints suggest that videodisc developers should select their topics and instructional approaches with considerable care, asking themselves such questions as, Is this the best way to accomplish this instructional goal? Is it the only way? Is this the least expensive way to accomplish this goal? If not, is the additional cost justified? Once a suitable topic is selected, another set of questions needs to be addressed, such as, Am I using this new medium in the best possible way? Have I fully explored the new instructional strategies made possible by this medium?

Students who studied selected biological topics by way of the interactive videodisc "The Development of Living Things," performed significantly better on a posttest and retention test (one week) than did students who received the information by way of classroom lectures, even though both groups had access to a text and syllabus and had no constraints on study time. Students also responded favorably to videodisc instruction, especially to the rich visual imagery and to various interactive strategies. In the long run the videodisc or some descendent technology may help restore a balance to our currently visually impoverished classrooms. Because of limitations of computer intelligence, however, we anticipate that for some time to come much of the

intelligent conversation that promotes learning will be provided by skilled and interested humans.

Note: As part of the National Science Foundation project, an executive summary videodisc was produced. It can be viewed on any of the current laser videodisc players (e.g., Pioneer or Sony) but is designed for and most satisfactorily experienced with an industrial player that provides some interaction through a remote-control keypad. Information about the availability of the executive summary disc can be obtained from Dr. C. Victor Bunderson, WICAT Systems, Inc., Box 539, 1875 South State Street, Orem, UT 84057.

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